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NATIONAL BUREAU OF STANDARDS REPORT

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THERMAL CONDUCTIVITY OF TWO FIBERGLASS-REINFORCED PLASTIC-IMPREGNATED SPECIMEN PANELS

by

Henry E. Robinson and Thomas W. Watson

to the

U.S. Naval Ordnance Laboratory
White Oak
Silver Spring, Maryland

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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NATIONAL BUREAU OF STANDARDS REPORT

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by

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to the

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1. INTRODUCTION

A series of comparative tests was initiated by Naval Ordnance Laboratory to investigate the effect of different testing apparatus and procedures on the values of thermal conductivity determined for specimens of plastic-impregnated fiber-glass reinforced panels. The test results reported herein were made on two specimens (DER-332 and E-787) specially prepared by Aerojet General Corporation for testing at Southern Research Institute, National Bureau of Standards, and Aerojet General Corporation, in that order. The measurements at NBS were authorized by NOL Project Order No. P.O. 3-0008 (J/O 958/1819/32050).

2. SPECIMENS

Two different panel materials were submitted for measurement, each in the form of a pair of specimens each approximately 14 by 14 by 0.5 inch in size. At NBS, each specimen was reduced in size to the central 9 by 9 inch square; the principal faces were not worked in any way.

When received, the pairs of specimens were identified by the numbers DER-332-A and DER-332-B, and E-787-A and E-787-B. These numbers were continued on the reduced specimens, and are used for reference in this report.

None of the reduced specimens was flat to 0.002 inch, nor uniform in thickness. Measurements of thickness (recorded to 4 figures) were made on each specimen by micrometer at three locations along each side of the central 7-inch square, and at the center and four corners of the central 4-inch square. These measurements are tabulated in Table 1.

As the tabulation averages show, the average specimen pair thickness over the central 4-inch square was a few mils less than the average pair thickness at the 7-inch-square trace, at room temperature, for both pairs. The average departure of the specimen face contours from two flat planes on both sides indicated by this difference can only be increased by the out-of-flatness, or warp, of the specimens, which may

TABLE 1

SPECIMEN THICKNESS DATA

	DER-332-A	DER-332-B	E-787-A	E-787-B
(Edges)	0.4828 in.	0.4824 in.	0.4592 in.	0.4826 in.
	.4833	.5057	.4638	.4827
	.4982	.5061	.4643	.4827
	.5020	.5073	.4636	.4828
	.5016	.5079	.4696	.4858
	.5072	.5099	.4868	.4927
	.5093	.5103	.4998	.4963
	.4980	.5090	.4970	.4953
	.4922	.5137	.4893	.4956
	.4932	.5155	.4813	.4917
	.4868	.5142	.4621	.4860
	.4833	.5080	.4582	.4834
Avg. 7-in.	(.4948)	(.5075)	(.4746)	(.4881)
Avg. for pair at 7-in.	(.5012)		(.4814)	
(Center)	.4864	.5077	.4684	.4850
	.4934	.5071	.4744	.4902
	.4828	.5090	.4640	.4832
	.4856	.5074	.4626	.4808
	.4896	.5100	.4725	.4853
Avg. over 4-in. sq.	(.4876)	(.5082)	(.4684)	(.4849)
Avg. for pair over 4-in. sq.	(.4979)		(.4767)	
Difference of pair averages	.0033		.0047	

change when a temperature difference exists face-to-face but could not be significantly reduced by the pressure exerted on the faces by the apparatus during tests. At room temperature, the specimens had different apparent amounts of warp:

DER-332-A: slightly out-of-flat, more than thickness difference.

DER-332-B: slightly out-of-flat, more than thickness difference.

E-787-A: saddle-shaped warp, out-of-flat >1/16 in. in two directions.

E-787-B: cylindrical warp, out-of-flat 1/16 in. in one direction.

3. METHOD AND PROCEDURE OF TEST

The thermal conductivity measurements were made in an 8-inch guarded hot plate apparatus (conforming to ASTM C177) having a 4-inch-square central metering section. The tests were conducted in a cabinet in air maintained at within one degree F of the specimen mean temperature; the exposed edges of the specimens were covered by about 1/2 inch of good blanket insulation.

Because of the expected low thermal resistance of the principal specimens, the tests were made using a composite-specimen technique which avoided need for thermocouples applied to the specimen faces. A resilient pad was interposed between each face of the specimen and the adjacent metal hot or cold plate of the apparatus, so that there was on each side of the hot plate a composite specimen consisting of pad, specimen, pad. The total temperature drop through the composite specimen was measured by means of permanent thermocouples installed in grooves in the metal faces of the cold and hot plates, and the test yielded as its result the average thermal resistance of the two composite specimens over the central 4-inch-square area. By subtracting from the average composite resistance the average thermal resistance of the two pads at the same mean temperature and total thickness, as determined in a separate test or tests using the same permanent plate thermocouples, the average net thermal resistance and conductivity of the principal specimens was calculated.

Two different kinds of resilient pad were used. The first was 1/8-inch thick commercial gum rubber (30 to 45 Durometer floating stock, Fed. Spec. MIL R-880A). In the form of an 8 by 8 by 1/8 inch sheet this rubber is practically incompressible under the pressure imposed by the plates of the apparatus (not more than 50 lb/ft^2), but it is resilient enough to conform to slight irregularities of contacting surfaces. However, as mentioned in the Discussion later, the rubber pads were not able to wholly compensate for the variable thickness and warp of the submitted specimens. For this reason, the tests were repeated using pads of an open-cell foam material (similar to Scott Paper Company "Skeletal Structural Industrial Polyurethane Foam") of about 50 pores per lineal inch and 1/4 inch in uncompressed thickness. As used, the 1/2-inch thickness of the foam pads of each composite specimen was compressed to about 0.07 inch. The average combined thickness of the two pads in the 4-inch-square metering area was determined by subtracting from the measured average distance apart of the flat hot and cold plates the average thickness of the principal specimens in the 4-inch-square central area as recorded in Table 1. This procedure compensates for warp of the specimens, and as much as feasible for the variable thickness of the specimens.

The thermal resistance of the foam pads, at various thicknesses and mean temperatures, was determined by a series of tests of the same pads alone, results of which are presented graphically in Figure 1. The resistances corresponding to thicknesses of the pads in the composite tests were obtained from the appropriate curve, with a slight correction for actual pad mean temperature ($dR/dT = -0.0006$ per deg F).

4. RESULTS AND DISCUSSION

The results of the measurements are summarized in Table 2. Because differences are involved, the data are given to four places.

The conductivities obtained for both submitted specimens using the rubber pads are definitely much lower than those obtained using the foam pads. The latter results are considered nearly correct.

Apart from the consideration that the conductivities obtained using rubber pads are of magnitude lower than would be anticipated for materials of this density and composition, there is internal evidence that these results are erroneously low. Table 2 shows that in the test at 66.8°F of the DER-332 specimens there was apparently a total thickness difference of 0.0043 inch not accounted for by the principal specimen and the two rubber pads. It is doubted that resilience of the pads would have accommodated to reduce the total gap to much less than 0.004 inch. An air gap of this thickness has a thermal resistance of 0.004/0.187, or 0.021 deg F per (Btu/hr ft^2). Reducing the net principal specimen resistance given in Table 2 for DER-332 at 66.8°F (0.1728) by 0.021 yields a specimen thermal conductivity of 3.27 Btu/hr ft^2(deg F/in.) which compares with the value 3.23 obtained with foam pads at 67.1°F. The values of conductivity of the submitted specimens deduced from the results of the tests with the rubber pads, by making a correction for the resistance of the putative air gap as above, are indicated in Table 2 by the values in square brackets. The fair agreement of these corrected values with the corresponding values obtained with the foam pads suggests that the foam pads compensated reasonably well for the non-uniform thickness and warp of the specimens, and that the results obtained with the foam pads are approximately correct.

Since the foam material had not been used here before for this purpose, the tests on Pyrex 7740 summarized in Table 2 were made for our own information. The good agreement of the results with the rubber and the foam pads on these flat and smooth Pyrex specimens, which had approximately the same low thermal resistance as the submitted specimens, indicates the acceptability of the foam material for this use, and also the general merit of the composite-specimen technique.

TABLE 2

SUMMARY OF NBS TESTS ON DER-332 AND E-787 (AND PYREX 7740)

With two 1/8-in. Rubber Pads

Specimen	DER-332 (128 lb/ft^3)		E-787 (131 lb/ft^3)	Pyrex 7740	
Mean temp., °F	66.8	127.4	68.5	30.4	122.2
Composite specimen R*	0.4198	.4266	.4762	.3665	.3660
Composite spec. thickness, in.	0.7549	.7615	.7506	1.2116	1.2197
Principal spec. thickness, avg., in.	0.4979	.4979	.4767	.9659	.9659
Total pad thickness, by diff., in.	0.2570	.2636	.2739	.2457	.2538
Total pad thickness, meas., in.	0.2527	.2539	.2527	.2465	.2529
Difference of pad thicknesses, in.	0.0043	.0097	.0212	-.0008	.0009
Total pad R*	0.2470	.2496	.2470	.2417	.2481
Net principal spec. R*	0.1728	.1770	.2292	.1248	.1179
Principal spec. thermal conductivity**	2.88	2.81	2.08	7.74	8.19
Temp. gradient in prin. spec., F/in.	22.2	22.8	30.7	8.3	7.8
Th. cond.** after correcting for air gap	[3.27]	[3.91]	[4.10]		

With two 1/4-in. Foam Pads, Compressed

Specimen	DER-332			E-787		Pyrex 7740	
Mean temp., °F	67.1	127.7	128.0	66.7	127.1	32.8	122.6
Composite specimen R*	0.4310	.4135	.4187	.4184	.3916	.4466	.3771
Composite spec. thickness, in.	0.5691	.5742	.5727	.5517	.5530	1.0412	1.0369
Principal spec. thickness, avg., in.	0.4979	.4979	.4979	.4767	.4767	.9659	.9659
Total pad thickness, by diff., in.	0.0712	.0763	.0748	.0750	.0763	.0753	.0710
Total pad R* (from Fig. 1)	0.2769	.2765	.2698	.2945	.2769	.3200	.2580
Net principal spec. R*	0.1541	.1370	.1489	.1239	.1147	.1266	.1191
Principal spec. thermal conductivity**	3.23	3.63	3.34	3.85	4.16	7.63	8.11
Temp. gradient in prin. spec., F/in.	19.7	17.5	19.1	16.6	15.3	8.4	7.9

* R = thermal resistance, deg F per (Btu/hr ft^2)

** Thermal conductivity, Btu/hr ft^2 (deg F/inch)

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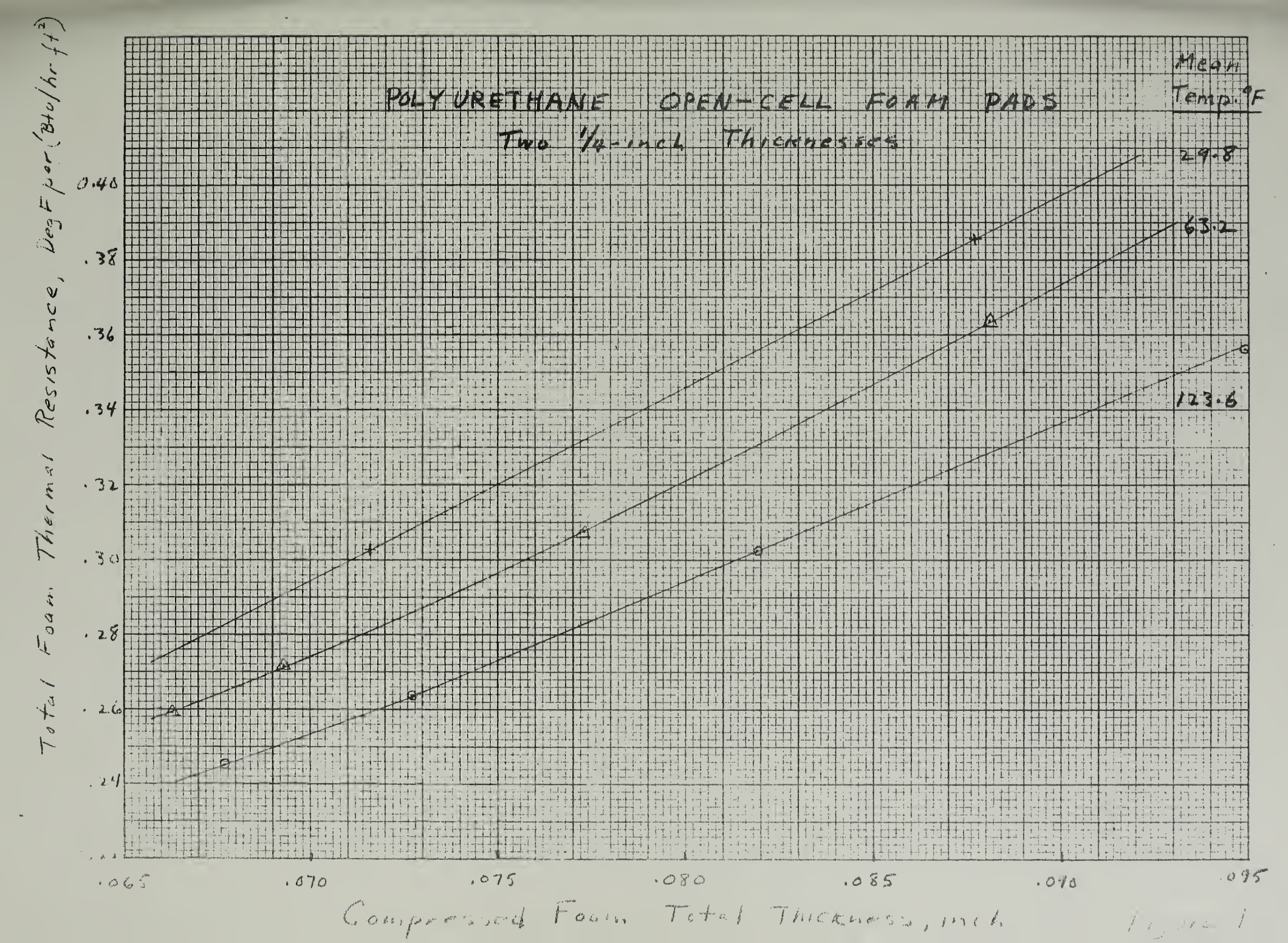
POLYURETHANE OPEN-CELL FOAM PADS
Two 1/4-inch Thicknesses
Mean Temp. °F
29.8
63.2
123.6
Total Foam Thermal Resistance, Deg F per (Btu/hr ft²)
0.40
.38
.36
.34
.32
.30
.28
.26
.24
.065
.070
.075
.080
.085
.090
.095
Compressed Foam Total Thickness, inch

Figure 1

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